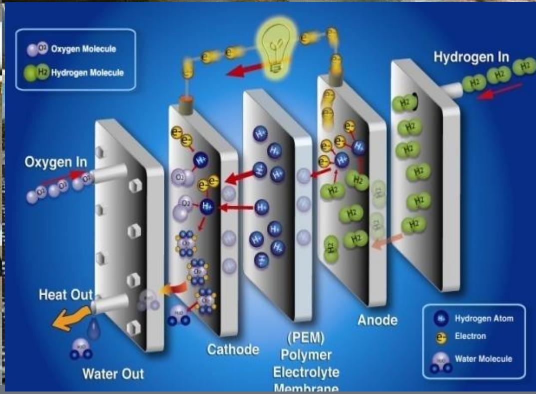
FUEL CELL TECHNOLOGIES OFFICE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Hydrogen and Fuel Cells Technical Advisory Committee and the DOE Hydrogen and Fuel Cells Program

November 21, 2014

Sarah Studer, PhD

ORISE Fellow
Fuel Cell Technologies Office
Energy Efficiency & Renewable Energy

Outline

- Hydrogen and Fuel Cells TAC
- DOE Hydrogen and Fuel Cells Program overview
- Fuel Cell Technologies Office
- FCTO activities relevant to Biomass RD&D

Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) Scope

To advise the Secretary of Energy on:

1. The implementation of programs and activities under Title VIII of EPACT
2. The safety, economical, and environmental consequences of technologies to produce, distribute, deliver, store or use hydrogen energy and fuel cells
3. The DOE Hydrogen & Fuel Cells Program Plan

Title VIII Sec. 802

"The purposes of this title are—

1) to enable and promote comprehensive development, demonstration, and commercialization of hydrogen and fuel cell technology in partnership with industry;
2) to make critical public investments in building strong links to private industry, institutions of higher education, National Laboratories, and research institutions to expand innovation and industrial growth;
3) to build a mature hydrogen economy that creates fuel diversity in the massive transportation sector of the United States;
4) to sharply decrease the dependency of the United States on imported oil, eliminate most emissions from the transportation sector, and greatly enhance our energy security; and
5) to create, strengthen, and protect a sustainable national energy economy. "

November 2014 HTAC Meeting Agenda

November 18

Time	Topic	Speaker
8:30 – 9:00 am	**HTAC Business** • Welcome for new members • Approval of November 18-19 meeting agenda • Reminder of 2015 meeting dates • Public comment period	John Hofmeister, HTAC Chair
9:00 – 10:00 am	**DOE Updates and Discussion** • DOE Leadership Updates • DOE Program and Budget Updates	Reuben Sarkar, Deputy Assistant Secretary for Transportation, DOE Dr. Sunita Satyapal, Director, Fuel Cell Technologies Office, DOE
10:00 – 10:45 am	**DOE Nuclear Energy Office Update**	Carl Sink, DOE, Office of Nuclear Energy
10:45 – 11:00 am	Break	
11:00 – 11:45 am	**GE Update on MW-scale SOFC**	Johanna Wellington, GE Global Research
11:45 – 12:15 pm	**H2USA Update**	Morry Markowitz, H2USA
12:15 – 1:15 pm	Lunch Break	
1:15 – 2:00 pm	**8-State ZEV MOU**	Matt Solomon, Northeast States for Coordinated Air Use Management (NESCAUM)
2:00 – 2:45 pm	**CA Activities Update and Hydrogen Infrastructure Challenges (e.g., contamination and metering)**	Tyson Eckerle, California Governor's Office
2:45 – 3:45 pm	**Linde Stations and Technology**	Michael Beckman, Linde
3:45 – 4:00 pm	Break	
4:00 – 5:00 pm	**FirstElement Hydrogen Stations**	Shane Stephens, FirstElement Fuel
5:00 – 5:30 pm	**2014 HTAC Annual Report Planning**	Bob Rose, HTAC

November 19

Time	Topic	Speaker
8:30 – 9:00 am	**Perspectives and Discussion on Hydrogen**	The Honorable Byron Dorgan
9:00 – 9:45 am	**HTAC Subcommittee Updates** • Retail Fueling Infrastructure • Manufacturing	Dr. Joan Ogden, HTAC Hal Koyama, HTAC
9:45 – 10:45 am	**Additive Manufacturing**	Blake Marshall, Advanced Manufacturing Office, DOE
10:45 – 11:00 am	Break	
11:00 – 11:15 am	**Review Hyundai Update**	HTAC (no presenter)
11:15 – 12:15 pm	**Other Business** (including discussion of future meeting topics) **Open Discussion**	John Hofmeister, HTAC Chair
12:15 pm	Adjourn	

HTAC Hydrogen Production Expert Panel Workshop

May 2012 event kick-off featured opening remarks from U.S. Secretary of Energy Steven Chu

EXPERT PANEL GOALS

- EVALUATE status and prospects for hydrogen production
- IDENTIFY key technologies and critical challenges in producing hydrogen for today's markets
- PRIORITIZE research and development needs
- STRATEGIZE how to best leverage R&D efforts among DOE Offices and Programs and with other agencies

WORKSHOP PROCESS

Coordination by Panel Steering Committee with broad expertise

↓

Panel Technical Experts present on opportunities and challenges

↓

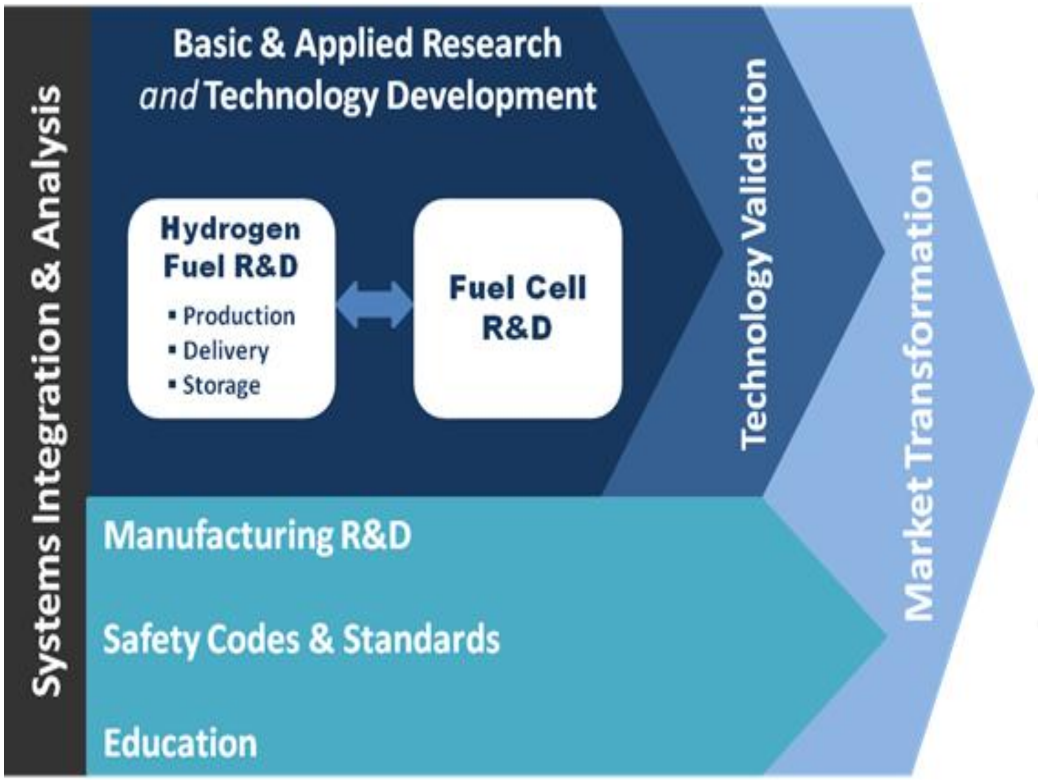
Breakout sessions of panelists and invited stakeholders identify key challenges and research priorities

Examples of Recommendations and Activities/Responses

- **Public-Private Partnerships - to focus on infrastructure**
- **Hydrogen for Energy Storage**
- **Coordination & Collaboration within DOE & with other agencies**

Recommendations Report and DOE response can be found at http://www.hydrogen.energy.gov/advisory_htac.html

Program Areas



2020 Targets by Application

	Vehicle	Stationary
Fuel Cell Cost	$40/kW	$1,000/kW* $1,500/kW**
Durability	5,000 hrs	80,000 hrs
H_2 Storage Cost (On-Board)	$10/kWh	
H_2 Cost at pump	<$4/gge	

*For Natural Gas
**For Biogas

Integrated approach to widespread commercialization of H_2 and fuel cells

Collaborations and Partnerships

R&D → Demonstration & Deployment → Accelerated Commercialization

USDRIVE – Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability

- Pre-Competitive R&D
- USCAR, energy companies, EPRI and utilities

California Fuel Cell Partnership; SC Hydrogen & Fuel Cell Alliance (www.SCHydrogen.org); H2I Hawai'i Hydrogen Initiative; Connecticut Hydrogen-Fuel Cell Coalition

- State Partnership and Collaboration

IPHE

- International Government Coordination
- 17 countries and European Commission

iea International Energy Agency

- Implementing Agreements
- 25 countries

H2FIRST – Hydrogen Fueling Infrastructure Research and Station Technology → **H2USA**

- National lab (SNL & NREL) led activities with industry

- Public-Private Partnership
- ~30 partners

In addition to above partnerships, advice & peer review provided by Federal Advisory Committee (HTAC), NAS, GAO, IG, AMR

Sustainable Transportation Sector

Sustainable TRANSPORTATION

- Transportation Efficiency
- Diverse Fuel Sources
- Domestic & Renewable

Hydrogen and Fuel Cells

Vehicles

Bioenergy

National Energy Goals
&
Climate Action Plan

Net Oil Imports

↓ 50% by 2020

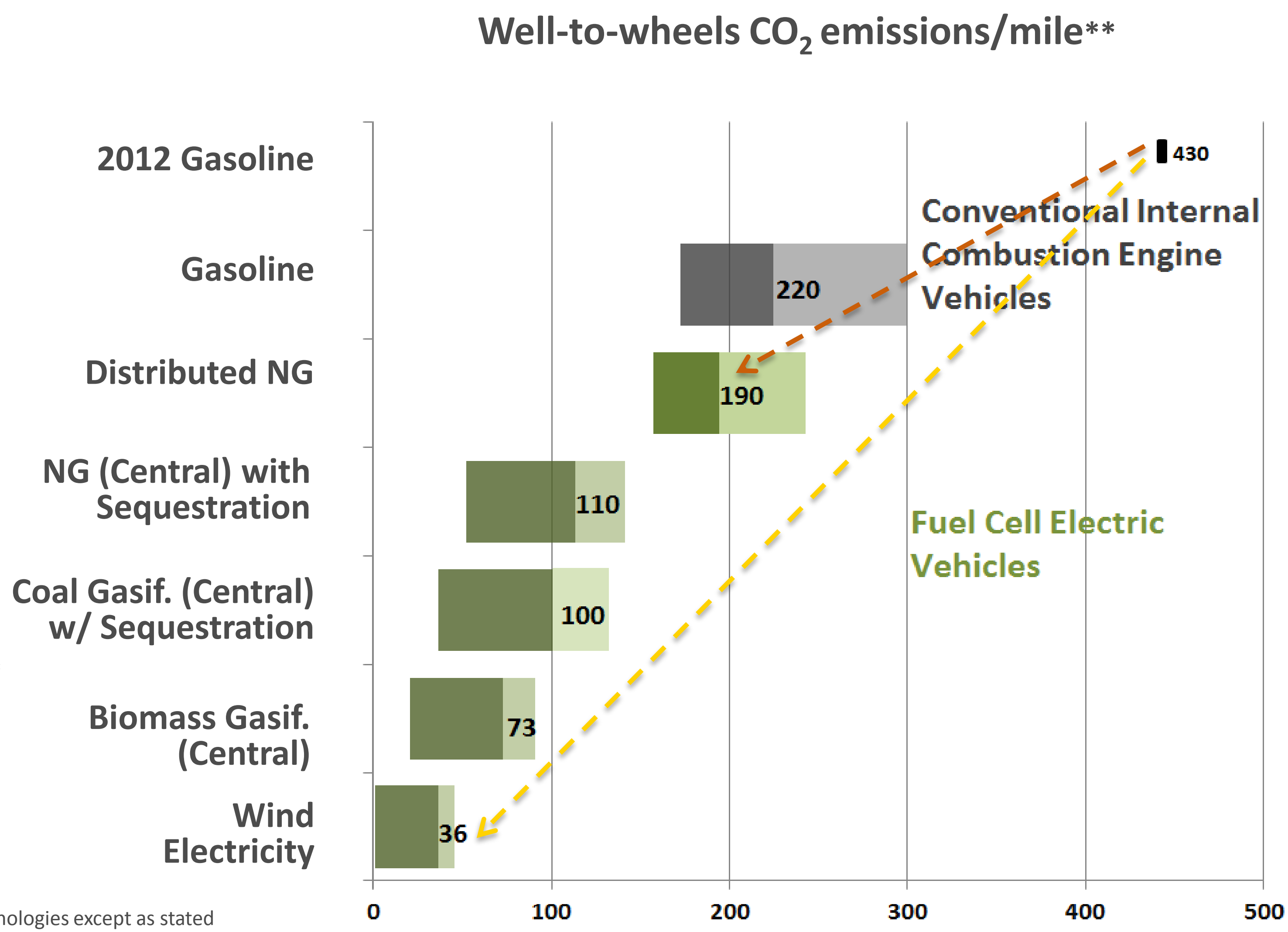
GHG Emissions

↓ 17% by 2020
>80% by 2050

FCEVs Reduce Greenhouse Gas Emissions

>50% from Distributed Natural Gas*

>90% from Renewables* (Wind)



*Compared to 2012 gasoline vehicle
** g CO2 equivalent; using 2035 technologies except as stated

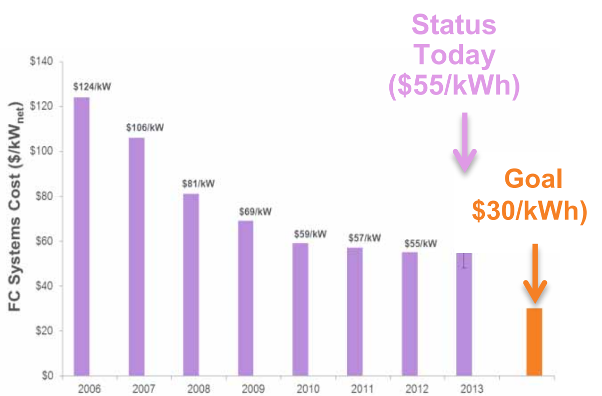
Substantial GHG reductions with H_2 produced from renewables

DOE Activities Span from R&D to Deployment

Research & Development

- *50% reduction since 2006*
- *80% electrolyzer cost reduction since 2002*

Fuel Cell System Cost*



**At 500,000-unit production*

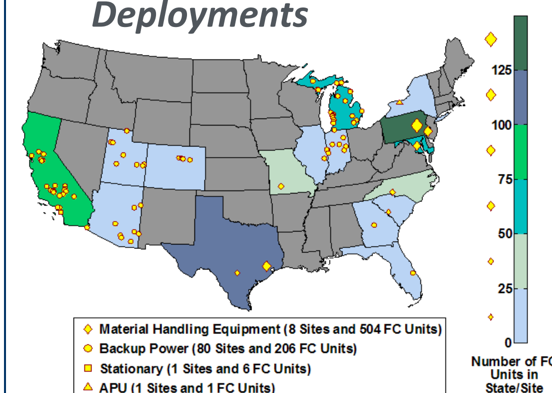
Demonstration

- *>180 FCEVs*
- *25 stations*
- *3.6 million miles traveled*
- *World's first tri-gen station*

  (250 kW on biogas, 100 kg/d H2 produced)

Deployment

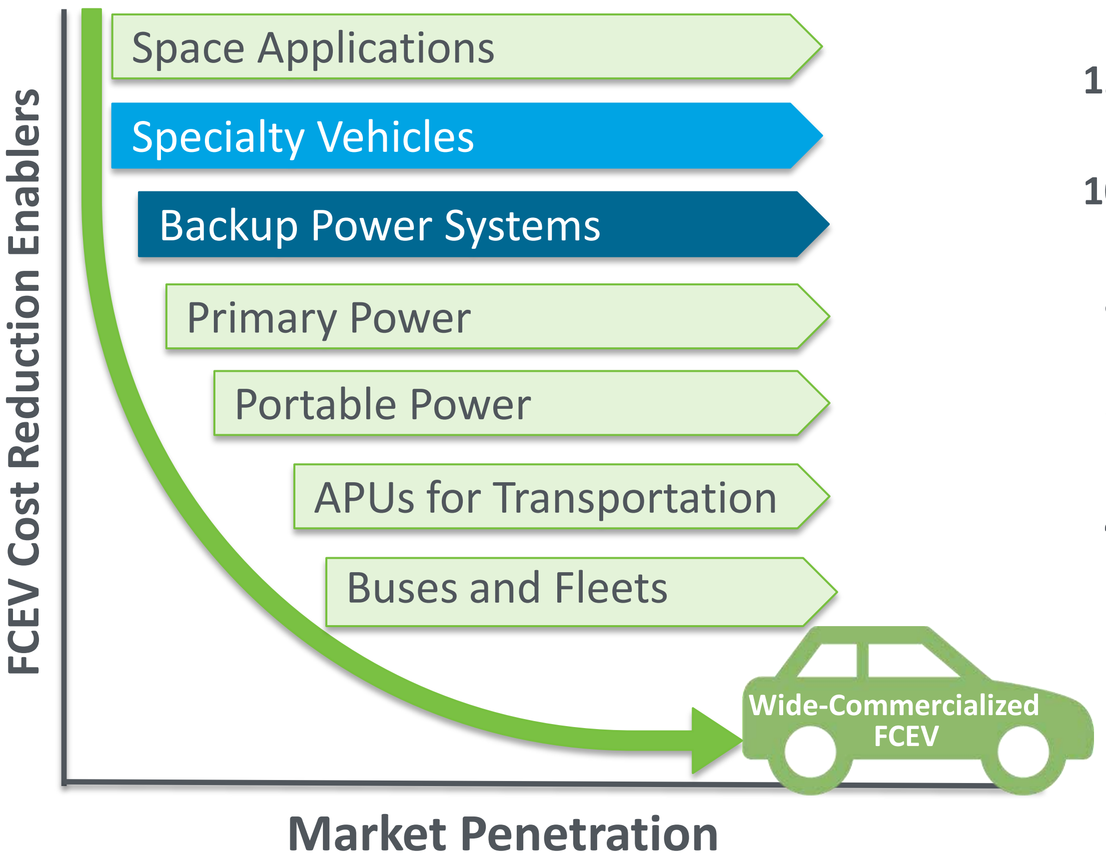
- *Government Early Adoption* (DoD, FAA, California, etc.)
- *Tax Credits: 1603, 48C*
- *~1,600 fuel cells deployed*
- *DOE Recovery Act & Market Transformation Deployments*



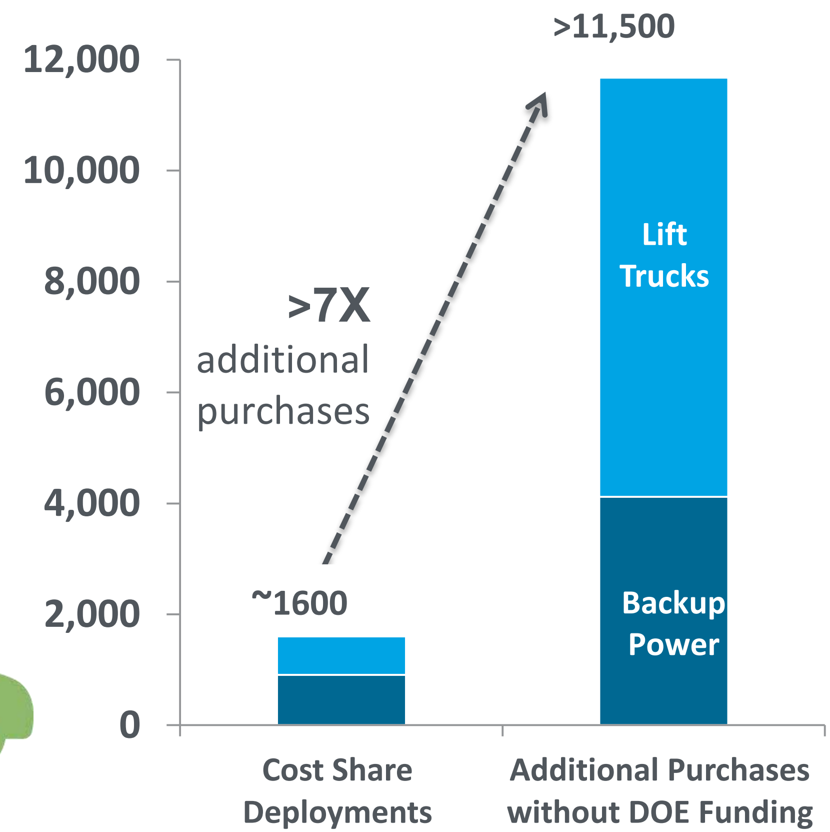
DOE's RDD&D activities are enabling commercialization of fuel cells

DOE Funding Impact on Early Market Purchases

FCEV Commercialization Strategy



DOE Cost-Shared Deployments and Additional Purchases



Catalyzing early markets enables broader commercialization of FCEVs

FCEVs are Here!

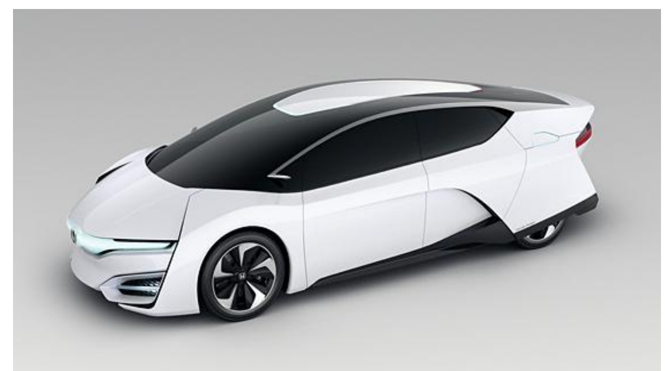
Available for Public Purchase soon….

Toyota Fuel Cell Electric Vehicle

Now Leasing…

Hyundai Tucson Fuel Cell SUV

In Auto Shows…



Honda Fuel Cell Electric Vehicle

OEMs bringing fuel cells to showrooms and driveways

H_2USA Public-Private Partnership to address H_2 Infrastructure Challenges

H_2USA

U.S. DEPARTMENT OF ENERGY
GlobalAutomakers
NESCAUM
Fuel Cell & Hydrogen Energy Association
AGA American Gas Association
California Fuel Cell Partnership – Driving for the Future
GM
HONDA The Power of Dreams
HYUNDAI
Mercedes-Benz
NISSAN
TOYOTA
AIR LIQUIDE
arc:HYDROGEN
Argonne National Laboratory
50%
EDTA Electric Drive Transportation Association
HNEI
HYDROGENICS Advanced Hydrogen Solutions
Intelligent Energy
ITM POWER Energy Storage | Clean Fuel
KOBELCO Kobelco Compressors(America), Inc.
The Linde Group Linde
Massachusetts Hydrogen Coalition
NACS
NREL National Renewable Energy Laboratory
NUVERA Making hydrogen make sense.
Pacific Northwest National Laboratory
PDC
plug power
PROTON The leader in on site gas generation.
Sandia National Laboratories
SRNL Savannah River National Laboratory
SCRA
CHRYSLER

3X increase in partners and growing since 2013

H_2 Infrastructure Development and Status

Nationwide

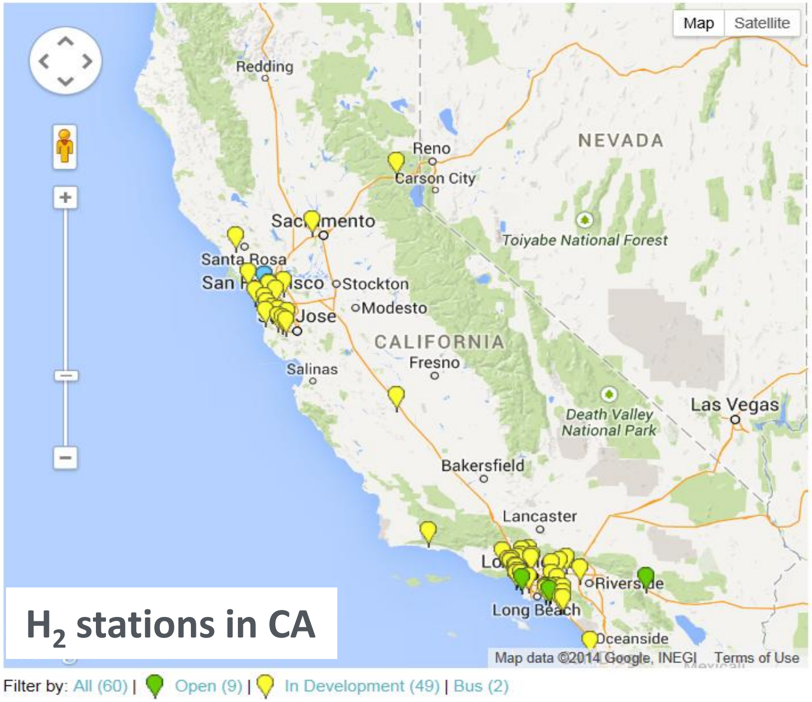
- **1500 mi.** of H_2 pipeline
- **>9M** metric tons produced/yr
- **~50 stations** (~10 public)

Other States

- **8-State MOU Members:** CA, CT, NY, MA, MD, OR, RI and VT
- **MA, NY, CT:** Preliminary plans for H_2 infrastructure and FCEVs deployment in metro centers in NE states.
- **Hawaii:** Public access refueling infrastructure on Oahu by 2020

California

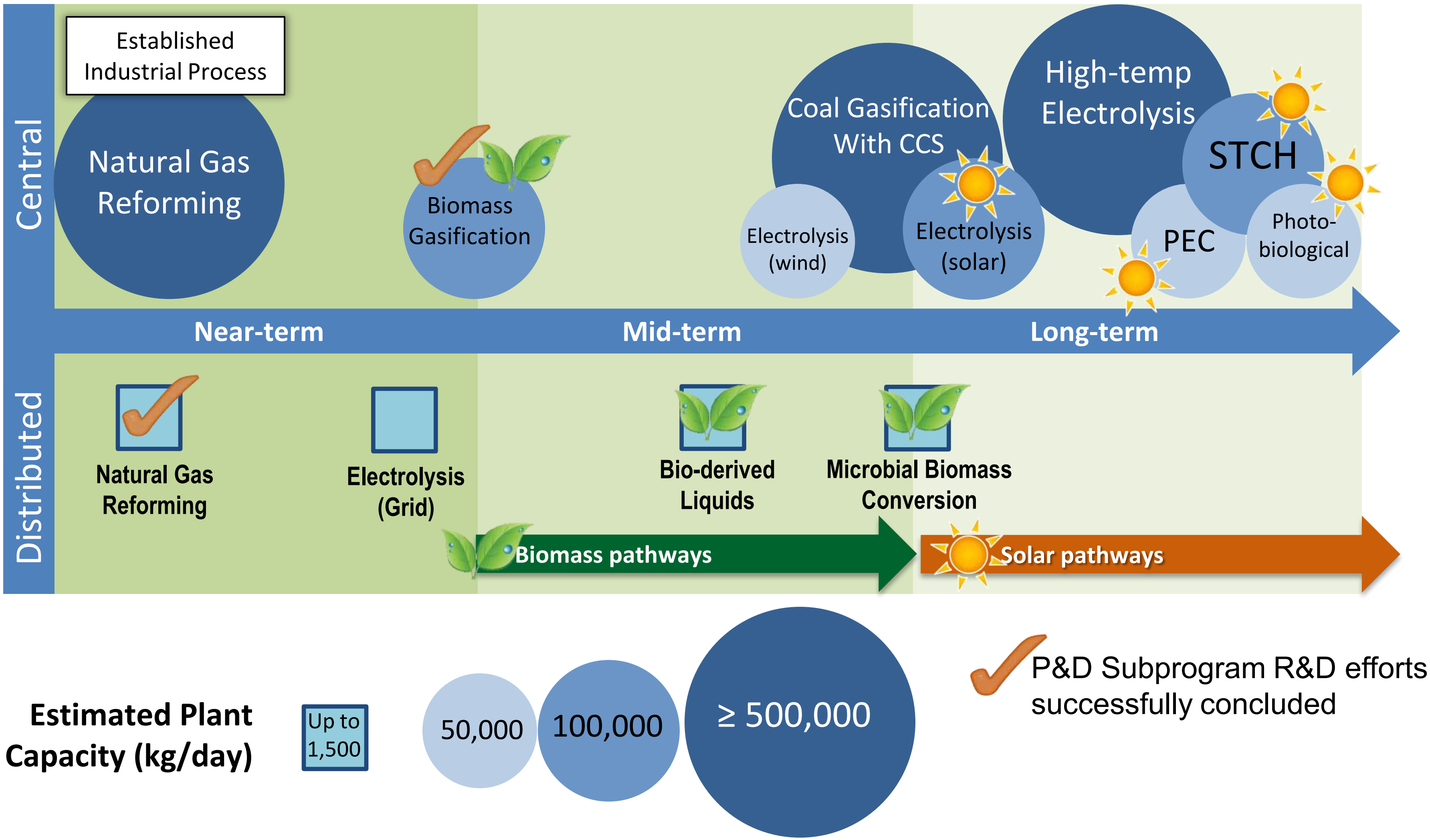
- **100 stations** - Goal
- **>~$70M** awarded
- **~$100M** planned through **2023**



H_2 stations in CA

California, NE States and Hawaii have H_2 infrastructure efforts underway

Hydrogen production pathways

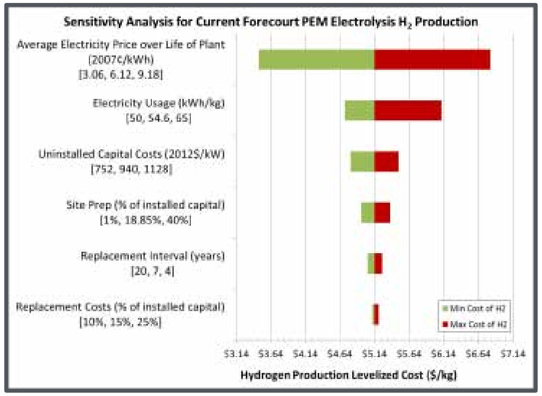


Develop technologies to produce hydrogen from clean, domestic resources at a delivered and dispensed cost of < $4/kg H_2 by 2020

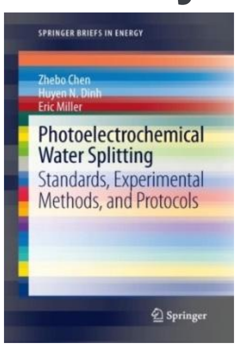
Biomass R&D relevant activities

Technoeconomic analysis

Fermentation case study in progress



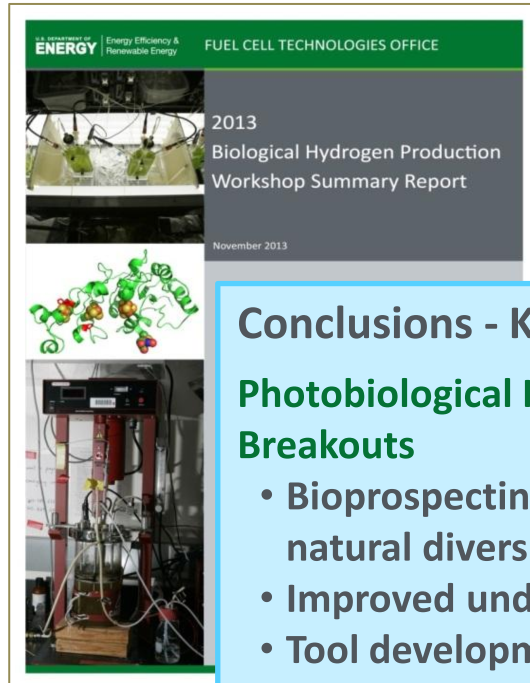
Pathway working groups



Biological Production group recently restarted

Inter- and intra-agency communication and collaboration

Workshops



Biological Hydrogen Production Workshop

Sponsored by FCTO

Hosted by NREL

Conclusions - Key Needs

Photobiological Hydrogen Production Breakouts

- Bioprospecting to take advantage of natural diversity
- Improved understanding of electron flux
- Tool development
- Potential methods to avoid oxygen co-production

Non-Light Driven Biological Hydrogen Production Breakouts

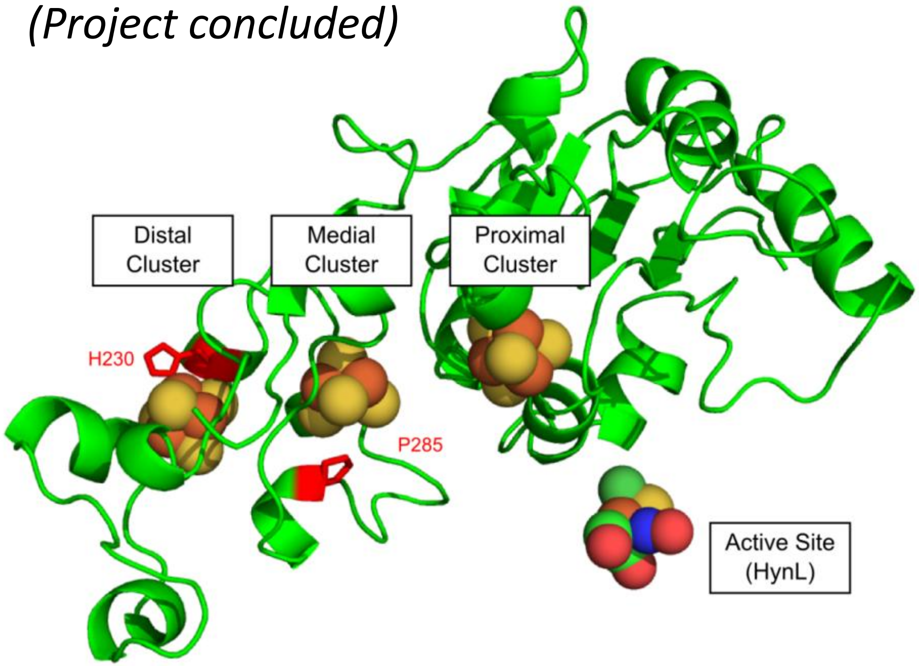
- Reactor design and scale-up
- Improved understanding of metabolism and energy flows
- Tool development

http://energy.gov/eere/fuelcells/biological-hydrogen-production-workshop

Cyanobacterial hydrogen production

Hydrogen from Water in a Novel Recombinant Oxygen-Tolerant Cyanobacterial System

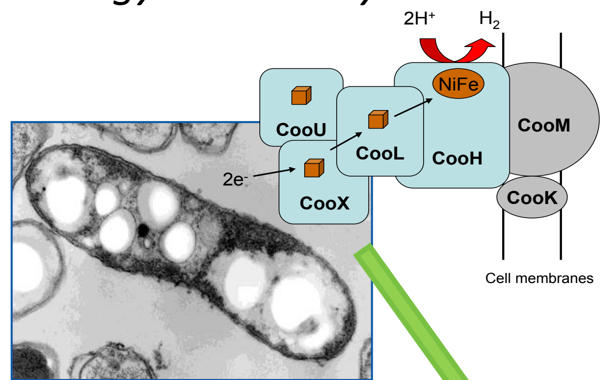
Philip Weyman, J. Craig Venter Institute (Project concluded)



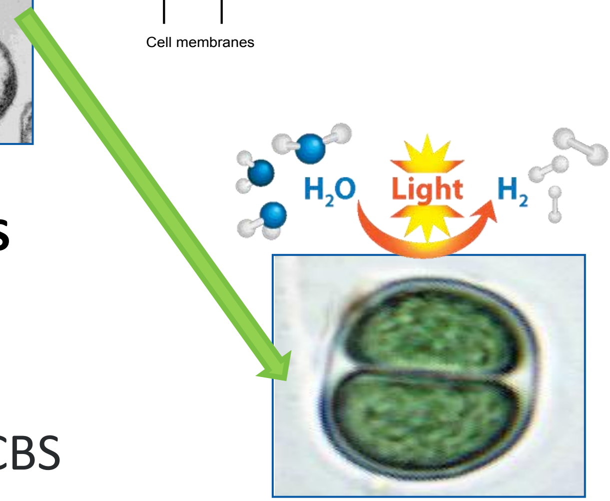
Expressed and improved activity of an environmentally isolated hydrogenase in *Synechococcus*

Improving Cyanobacterial O2-Tolerance using CBS Hydrogenase

Pin-Ching Maness, National Renewable Energy Laboratory



***Rubrivivax gelatinosus* CBS**



Synechocystis

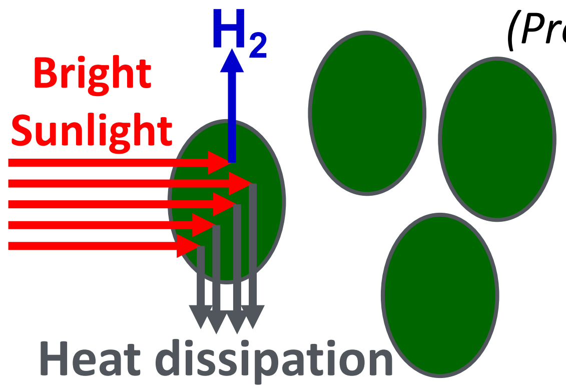
Transferring CBS strain's hydrogenase into *Synechocystis*

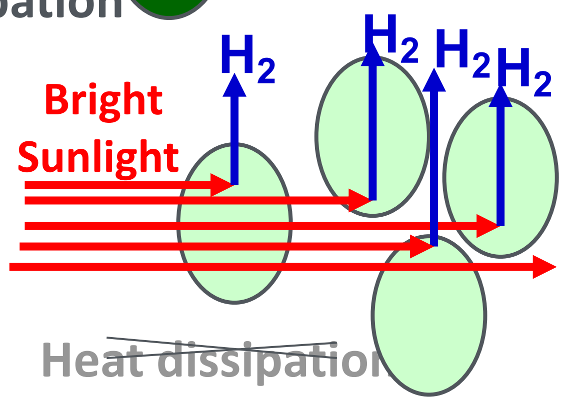
Algal hydrogen production

Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures

Tasios Melis, University of California, Berkeley

(Project concluded)

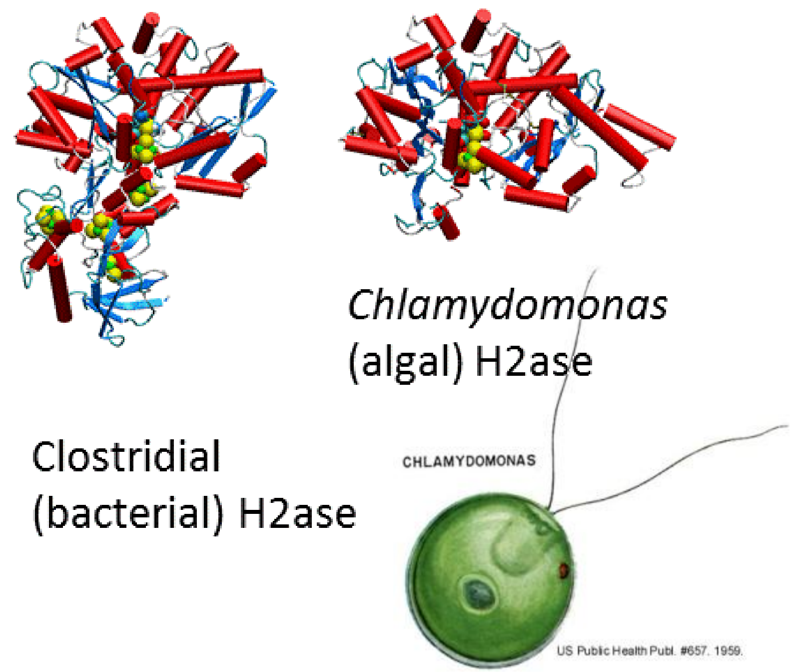




Shortened chlorophyll antenna to reduce excess photon collection, improving light utilization by cultures

Biological Systems for Hydrogen Photoproduction

Maria Ghirardi,
National Renewable Energy Laboratory

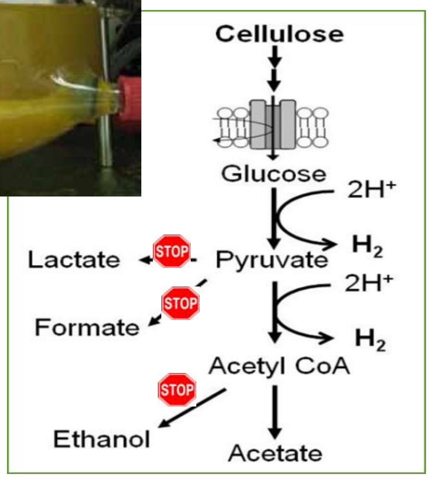


Integrating additional improvements into strain with demonstrated light-driven hydrogen production from non-native hydrogenase

Microbial Biomass Conversion

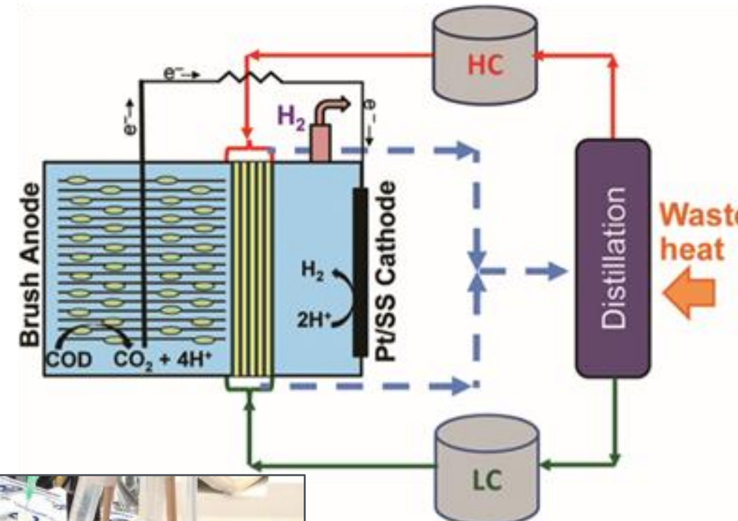
Fermentation and Electrohydrogenic Approaches to Hydrogen Production

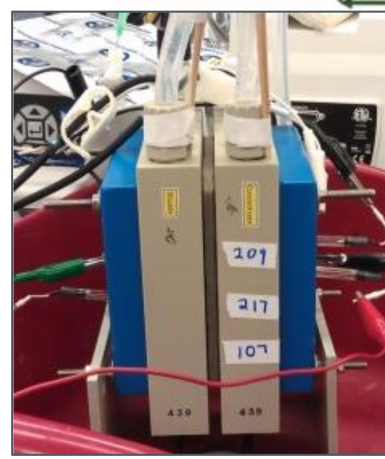
Pin-Ching Maness, National Renewable Energy Laboratory



Improving hydrogen production from pretreated corn stover fermentation

Bruce Logan, Penn State



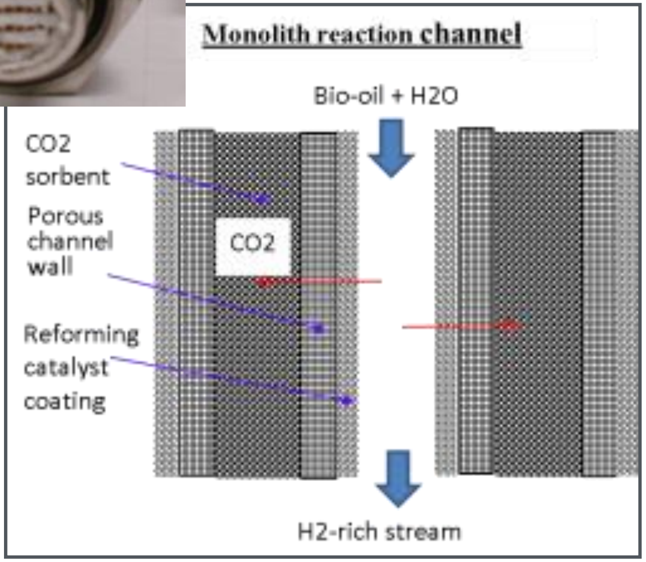


Utilizing fermentation waste water to produce hydrogen from MRECs

Utilization of bioderived feedstocks

Monolithic Piston-Type Reactor for Hydrogen Production through Rapid Swing of Reforming/Combustion Reactions

Wei Liu, Pacific Northwest National Laboratory



Producing hydrogen from bio-oils using a scalable, compact monolith reactor system

Bio-Fueled Solid Oxide Fuel Cells

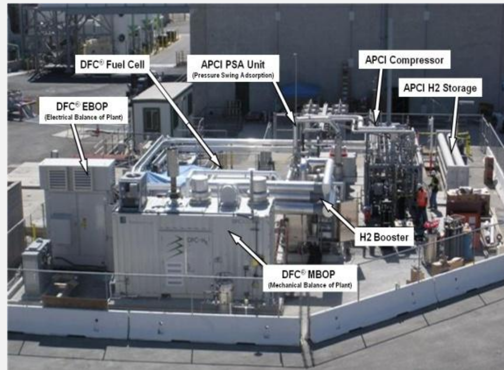
Gökhan Alptekin, TDA Research, Inc.

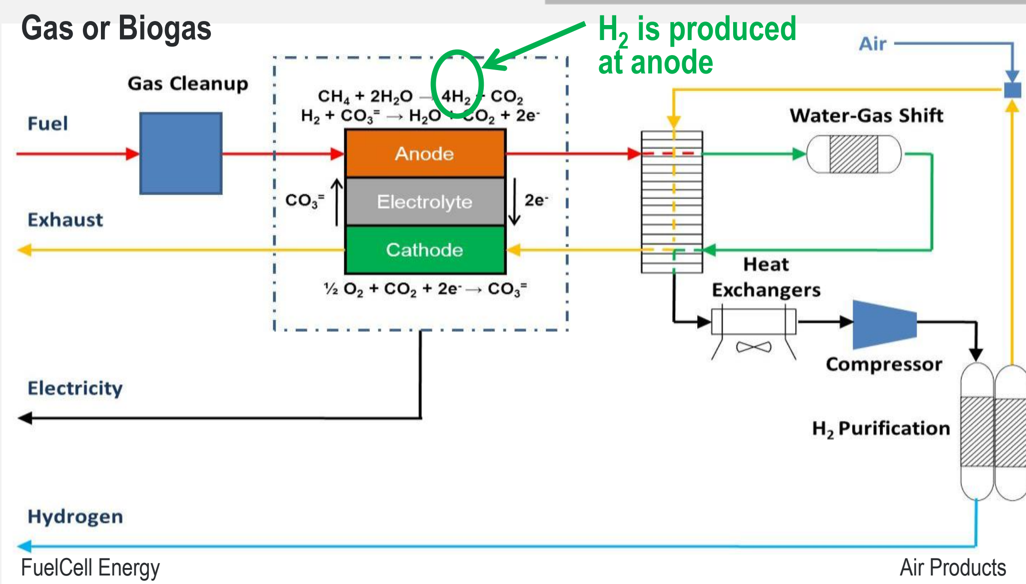
Gas clean-up system to enable the use of biogas in high temperature fuel cells

Tri-Generation from biogas

Demonstrated world's first Tri-generation station

- Demonstrated co-production of electricity and hydrogen with 54% efficiency
- Uses biogas from wastewater treatment plant





Co-funded by DOE/FCT and multiple partners

Fountain Valley demonstration

- ~250 kW of electricity
- ~100 kg/day hydrogen capacity (350 and 700 bar), enough to fuel 25 to 50 vehicles.

Tri-Generation co-produces power, heat and hydrogen. World's First Fuel Cell and Hydrogen Energy Station demonstrated in Orange County (DOE/FCT project)

Going Forward

- **Continue to promote and strengthen R&D activities**
  - H_2, fuel cells, safety, manufacturing, etc.
  - Cost, performance, durability need to be addressed
- **Conduct strategic, selective demonstrations of innovative technologies**
  - Industry cost share and potential to accelerate market transformation
- **Continue to conduct key analyses to guide RD&D and path forward**
  - Life cycle cost; infrastructure, economic & environmental analyses, etc.
- **Leverage activities to maximize impact**
  - U.S. and global partnerships
  - H2USA: Public-Private partnership to enable widespread commercialization of H_2 vehicles in the United States

Thank You

Dr. Sarah Studer

ORISE Fellow

Fuel Cell Technologies Office

Sarah.Studer@ee.doe.gov

hydrogenandfuelcells.energy.gov

Backup slides

Hydrogen & Fuel Cell Budget

Key Activity	FY 2014 ($ in thousands) Request	FY 2014 ($ in thousands) Approp.	FY 2015 ($ in thousands) Request
Fuel Cell R&D	37,500	32,422	33,000
Hydrogen Fuel R&D	38,500	34,467	36,283
Manufacturing R&D	4,000	2,879	3,000
Systems Analysis	3,000	3,000	3,000
Technology Validation	6,000	6,000	6,000
Safety, Codes and Standards	7,000	6,909	7,000
Market Transformation	3,000	2,841	3,000
NREL Site-wide Facilities Support	1,000	1,000	1,700
SBIR/STTR	-------	3,410	TBD
Total	$100,000	$92,928	$92,983

Office	FY 2014
EERE	$93M
Basic Science[2]	$20M to $25M
Fossil Energy, SECA	$25M
ARPA-E[3]	$33M

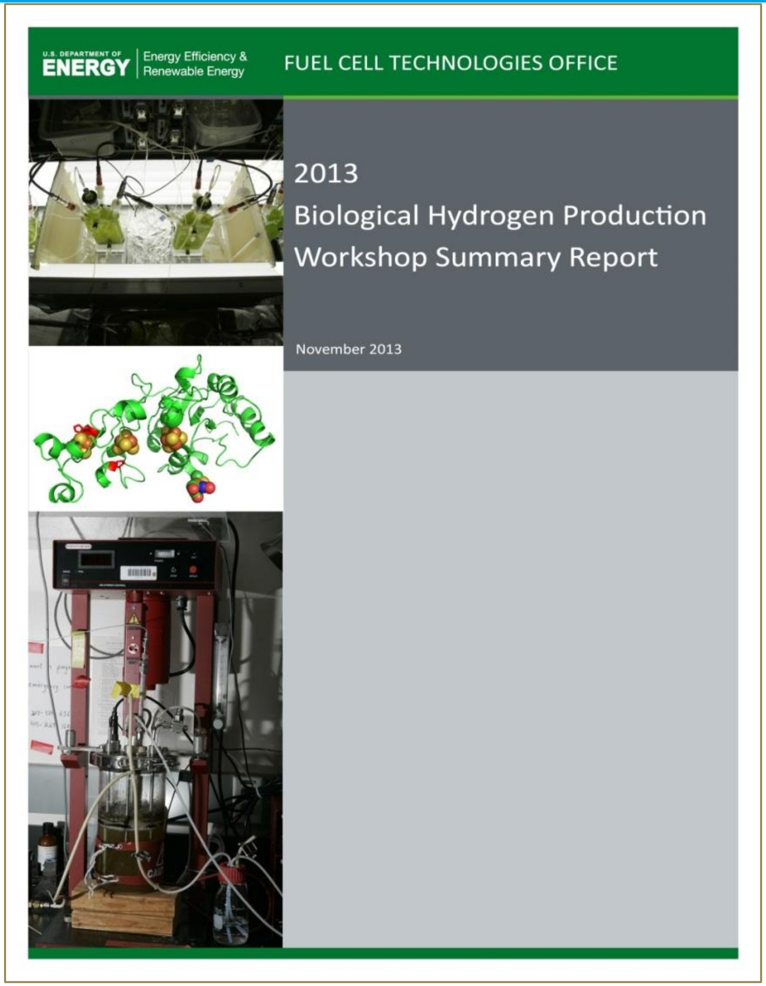
FY14 DOE Total: ~$175M

Consistent R&D funding request and appropriations in recent years

Hydrogen and Fuel Cell Summary FY15 Senate and House Language

SENATE	HOUSE
Total recommendation: $93,000,000	**Total recommendation: $100,000,000**
• DOE should analyze, research and make suitable investments in order to transform the size, cost, scalability (including modular stations), and interoperability of new retail hydrogen stations. • DOE should focus on consumer acceptance and strategic locations.	Technology Validation: • $5,000,000 of funding above the request is for testing and analysis of fuel cells as industrial-scale energy storage devices, with validation and testing using full-scale testing and demonstration capabilities. • Recommends that DOE leverage national laboratory, university, and regional stakeholder partnerships and capabilities, including at-scale grid infrastructure, modeling expertise, extreme environment testing capabilities, and public-private partnerships.
No specific direction on allocation of $93M (consistent with request).	Advanced demonstration and deployment: • $2,017,000 above the request is for demonstration and deployment activities that validate commercial viability, including material handling equipment, ground support equipment, refrigerated trucks, auxiliary power units, and associated hydrogen infrastructure.
H2USA: Committee is encouraged by the collaborative approach reflected in H2USA.	No direction.

Biological Hydrogen Workshop



September 24-25, 2013
Sponsored by Fuel Cell Technologies Office
Hosted by National Renewable Energy Laboratory

Photobiological Breakouts

- **Photolytic Hydrogen Production**
- **Photofermentative Hydrogen Production**
- **Biohybrid Systems and Enzyme Engineering for Hydrogen Production**

Conclusions - key needs

- Bioprospecting to take advantage of natural diversity
- Improved understanding of electron flux
- Tool development
- Potential methods to avoid oxygen co-production

Non-Light Driven Biological Breakouts

- **Fermentative Hydrogen Production**
- **Hydrogen Production by MxCs**
- **Genetic and Metabolic Engineering for Hydrogen Production**

Conclusions - key needs

- Reactor design and scale-up
- Improved understanding of metabolism and energy flows
- Tool development

Report and presentations can be found at: http://www1.eere.energy.gov/hydrogenandfuelcells/wkshp_bio_h2_production.html

Workshop Report: Major Conclusions

Photobiological Hydrogen Production

Bioprospecting to take advantage of natural diversity

- Hypothesis- and target-driven studies could allow researchers to identify and understand potentially useful enzyme variations generated by nature that may allow for improved hydrogen production

Improved understanding of electron flux

- Understanding the energy flows within cells, both those that directly lead to hydrogen production, and those that can indirectly affect production, would allow better targeting of genetic engineering

Tool development

- Tools for manipulating many hydrogen-producing strains are currently limited, and developing these would enable researchers to improve strains of interest

Potential methods to avoid oxygen co-production

- Co-production of oxygen during photolysis damages the hydrogen-producing enzymes and causes practical problems for safety and hydrogen harvesting, so developing methods that avoid simultaneous co-production would be beneficial

Non-Light Driven Biological Hydrogen Production

Reactor design and scale-up

- Reactors will need to be designed to provide conditions that maximize microbial production, can be integrated into feedstock sources such as biorefineries, and support high production rates at large scale

Improved understanding of metabolism and energy flows

- Better understanding of metabolic pathways involved in feedstock breakdown and hydrogen production, and ion transfers in MxCs, particularly under relevant conditions, will be needed to guide optimization of the microbial characteristics and reactor design and conditions

Tool development

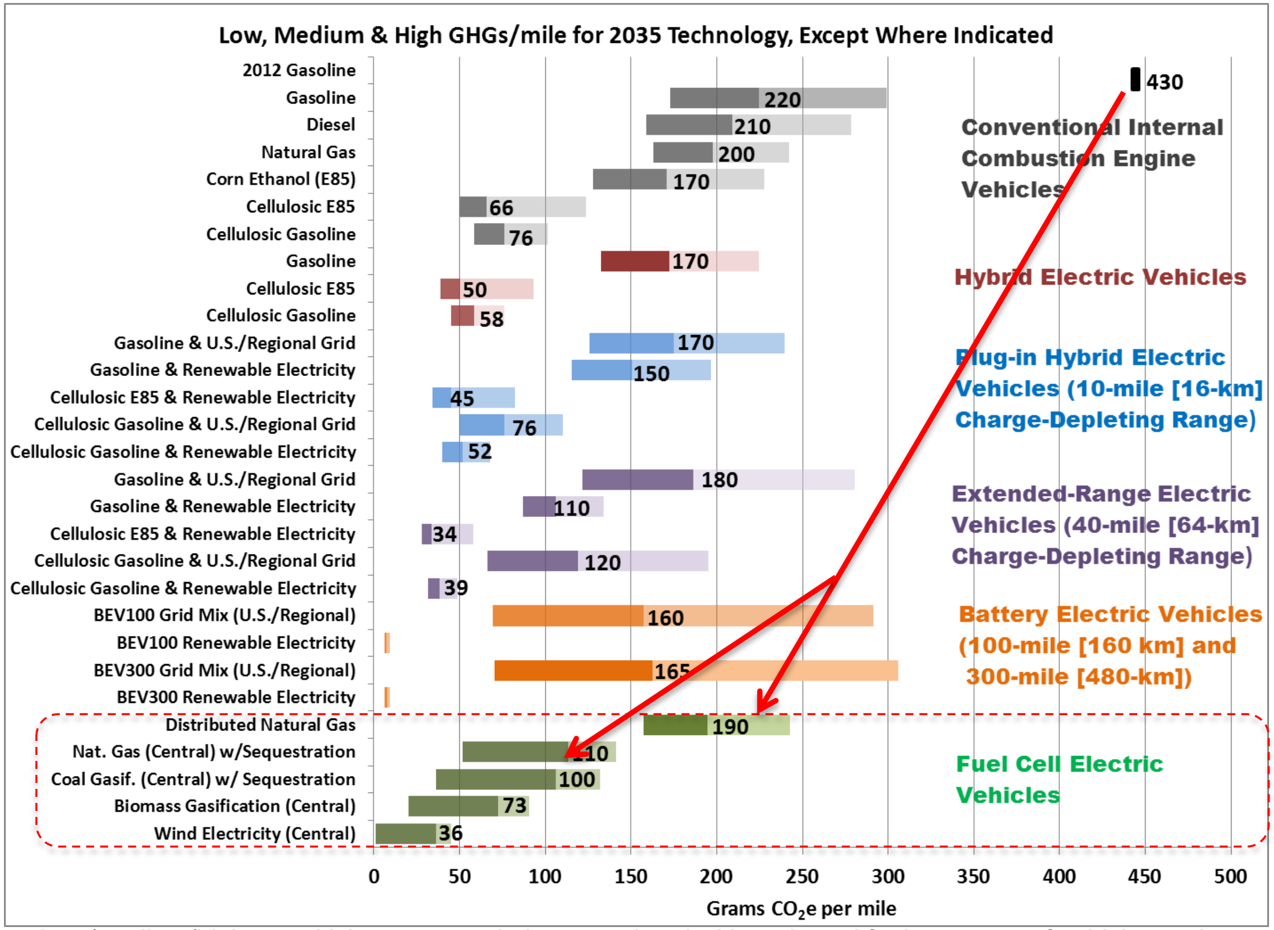
- Tools for manipulating many hydrogen-producing strains are currently limited, and developing these would enable researchers to improve strains of interest

Well-to-Wheels GHG Emissions

- **Updated, peer-reviewed analysis (EERE multi-Office coordination)**
- **Hydrogen from natural gas can reduce GHG emissions by >50% (significantly more if centrally produced and with carbon capture)**

Well-to-Wheels Greenhouse Gas Emissions for 2035 Mid-Size Car

(Grams of CO2-equivalent per mile)



Low/medium/high: sensitivity to uncertainties associated with projected fuel economy of vehicles and selected attributes of fuels pathways, e.g., electricity credit for biofuels, electric generation mix, etc.

See reference for details:
http://hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf

Analysis by Argonne National Lab, National Renewable Energy Lab and EERE (Vehicles, Fuel Cells, & Bioenergy Technologies Offices) shows benefits from a portfolio of options

HTAC Members

Academia

- Anthony Eggert, UC-Davis
- Dr. Timothy Lipman, UC-Berkeley
- Dr. Joan Ogden, UC-Davis
- Dr. Levi Thompson, U. of Michigan

Associations/Non-Profits

- **Catherine Dunwoody, California Fuel Cell Partnership → CARB**
- **Dr. Kathryn Clay, American Gas Association**
- Robert Rose, Fuel Cell and Hydrogen Energy Association→ BTI

Environmental

- **Margo Oge, Environmental Protection Agency (ret'd)**

Fuels Production

- John Hofmeister, Shell Oil Company (ret'd)

Government

- Dr. Peter Bond, Brookhaven National Laboratory
- Dr. Richard Carlin, Office of Naval Research
- Maurice Kaya, State of Hawaii (ret'd)
- **Commisioner Janea Scott, California Energy Commission**

Stationary Power

- Harol Koyama, H2 PowerTech

Transportation

- Charles Freese, GM
- Dr. Alan Lloyd, ICCT (ret'd)

Utilities (Electricity & Natural Gas)

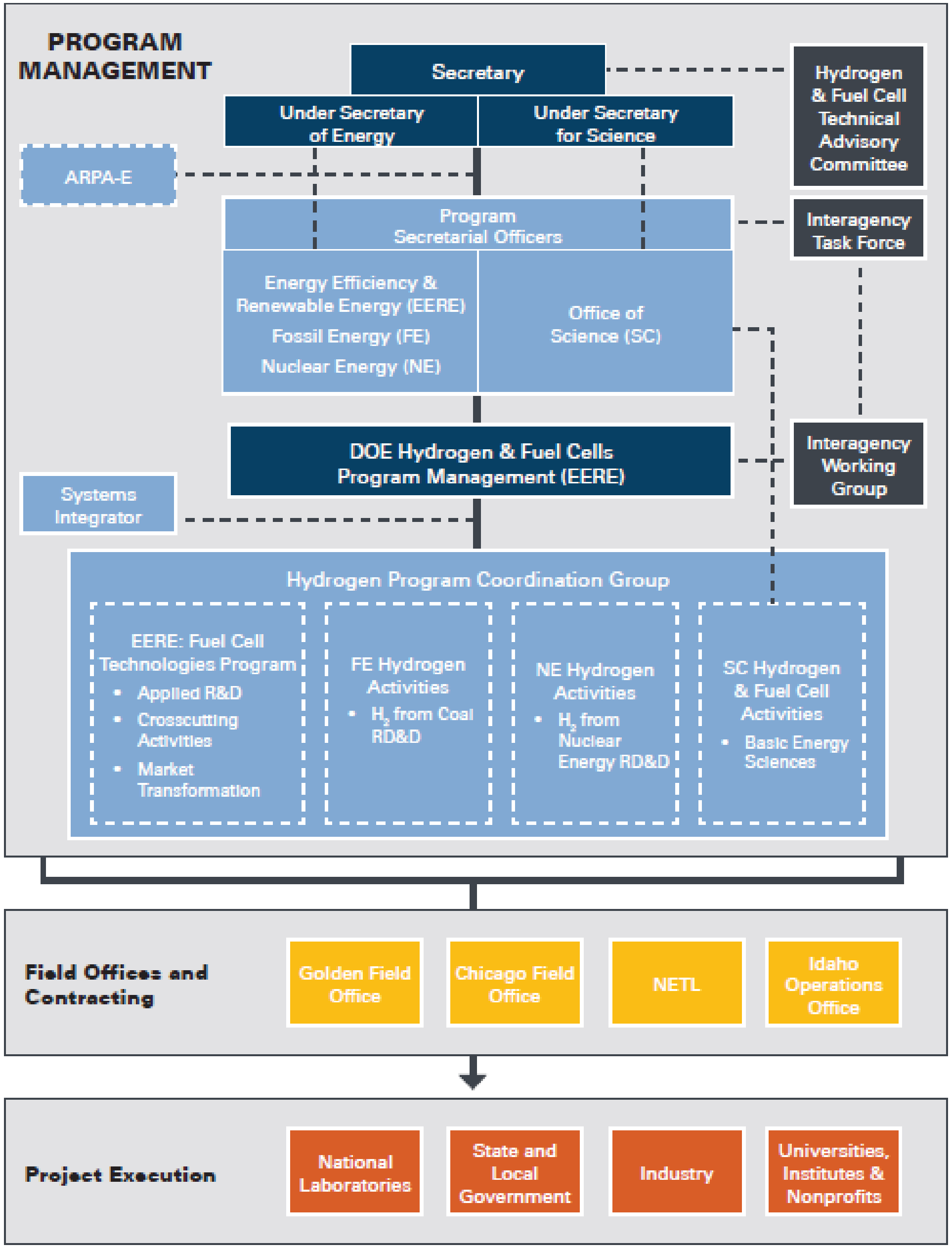
- Frank Novachek, Xcel Energy

Venture Capital

- **Paul Leggett, Morgan Stanley→ Mithril Capital**
- Robert Shaw, Aretê Corporation

New Members

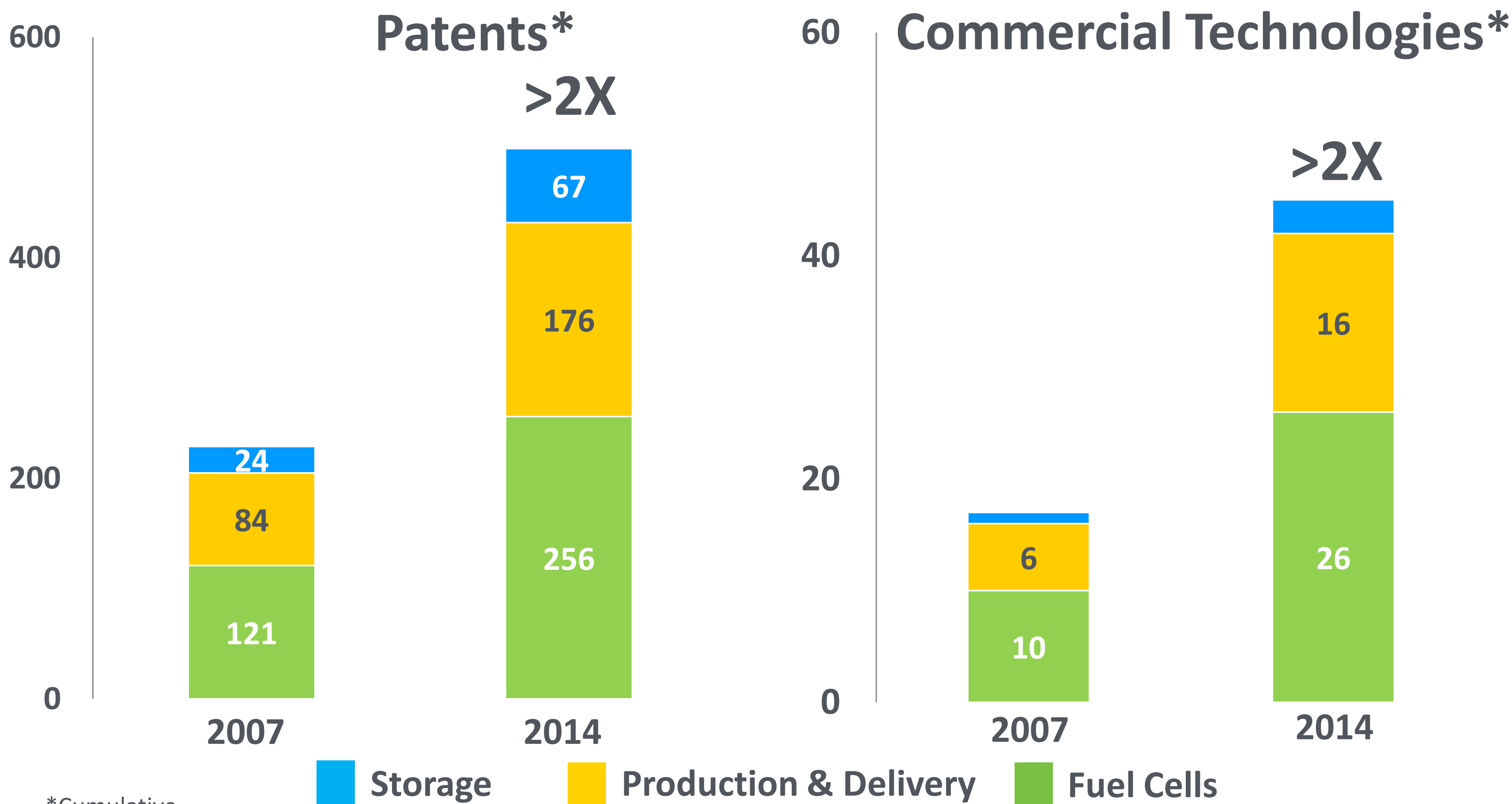
Overall Hydrogen and Fuel Cells Program Organization



History:

- Hydrogen Program (renamed Hydrogen and Fuel Cells Program in FY10) includes EERE, FE, NE and SC
- EERE is lead for overall Program (since 2004)
- Program conducts monthly coordination working group meetings across EERE, FE, NE, and SC, and has an integrated strategic plan (Program Plan)
- Each office has its own multiyear RD&D plan

Technology Innovation and Commercialization



*Cumulative

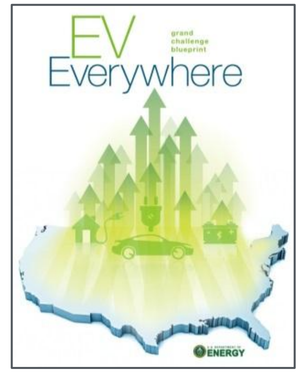
DOE funding has led to ~500 patents and 45 commercial technologies

Transportation Sector Priorities

Core Focus

- Vehicle Electrification
- Materials Lightweighting
- Advanced Combustion
- Drop-in Biofuels
- Community Partner Projects
- Fuel Cell Technology
- Hydrogen Infrastructure
- Crosscuts (multi-office)

Programs & Initiatives



Workplace Charging Challenge
U.S. DEPARTMENT OF ENERGY

Clean Cities
U.S. Department of Energy

H_2USA

H_2FIRST

Portfolio of technology R&D and market transformation activities